Listen to the Voice of Geology

Possible Implications of the Recent Geological Events of the Tirunelveli District of Tamil Nadu on the Safety Profile of the Kudankulam Nuclear Power Plant

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Listen to the Voice of Geology

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Contents

Dedicated
to
Meghnad Saha
who
dreamed
a different kind
of
Nuclear India

Preface

This book grew out of the general wish that the safety of our lives have to be kept in our mind whenever we strive to reap the fruits of Science and Technology. It discusses the safety issues related to the Kudankulam Nuclear Power Project, in particular. It puts forward those facts of the local geology, that the proponents of the Power Plant have failed to consider. It discuses the possible implications of such a gross negligence.

The Nuclear Power Corporation (NPCIL) signed a contract with the ATOMSTROYEXPORT of Russia to commission the Detailed Project Report (DPR) in the year 1998. This report was completed in the end of the year 2000. It has the Preliminary Safety Analysis Report (PSAR) as one of its components. This Safety Analysis Report is the nucleus that shall ensure that the Reactors function with a high degree of Safety.[1] The Atomic Energy Regulatory Board (AERB) is said to have given its approval for this PSAR.

It so happened that it was in the same year when the DPR was commissioned, certain strange geological events started occurring in the Thirunelveli District of Tamil Nadu. Kudankulam is located in the Radhapuram taluk of this district. As the work on the DPR progressed, so did these strange geological events.

Commissioning of the Detailed Project Report for the Kudankulam Nuclear Power Project and the Occurrences of the Rock Melt Extrusions happened simultaneously.

Molten Rocks were extruded from a crevice that developed in the land suddenly on the night of August 5, 1998 at the Animal Farm, in a place called Abishekappatti near the Thirunelveli town. This event was followed by a similar event in a village called Parappadi near Nanguneri town of the same district on 6 August 1998. A concrete electrical post was melted completely at its bottom half during the Abishekappatti incident. The first place is about 60 kilometers north west of Kudankulam. The second place is about 30 kilometers north west of the reactor site. It took 48 hours for the Abishekappatti rock melt to cool down.

A similar event occurred at a place called Thiruppanikarislkulam, which is located near Abishekappatti, the next year. It was on September 29th that year. It took nearly 12 hours for this melt to cool down.

The year 2000 didn't witness any such events. The DPR was said to have been completed and submitted to the NPCIL in the end of 2000. The next big event that followed this was the boomi puja for the reactor site in October 2001. Again, a similar Rock Melt Extrusion (RME) occurred at a place near Surandai town of the same district on November 24th 2001. This town is located by the side of the Thirunelveli-Thenkasi state highway and is about 75 kilometers north west of Kudankulam.

All through these four years, whenever these events happened, there was much panic among the local populace. However, these events did not cause any large scale damage. However, they attracted the attention of the media like no other event; besides all this, these sites found a regular stream of visitors from schools, colleges and the lay public alike.

It is a strange coincidence that all these events had occurred near electric posts. Hence, it was declared by the local authorities that these events have occurred only due to the electrical leakage from the transmission lines of these posts. So, whenever such events occurred, it almost became a habit and a ritual for the local authorities to replace the electrical posts that were

standing nearby and forget about the incidence later.

The NPCIL was not much interested about the above events throughout these years. It is highly doubtful, whether the NPCIL had ever informed the ATOMSTROYEXPORT about the regular occurrence of these events. Even if we believe that the NPCIL had informed the Russian organisation about these strange happenings, ATOMSTROYEXPORT didn't bother to release even a press statement on this issue.

Researchers have identified in the year 2001, fourteen Carbonatite Dykes at Kudankulam. This discovery is of immense importance to the Safety of the Kudankulam Nuclear Power Plant. What this means is that, this area has an Unstable Crust, with a fault line that may be of a very deep throw.

It was nearly two years since the first incident occurred, two research papers on this event appeared in the Journal of the Geological Society of India.[2] That was in the year 2000. The first and the second papers were followed by a third research paper in 2001, by a different group of investigators.[3] However, these researchers didn't belong to the NPCIL or the ATOMSTROYEXPORT, but they were Geologists working in a nearby college and a University and in the Department of the State Geological Survey. As the NPCIL has a seismograph installed at Erwadi, the officials looking after it also joined the first team of authorities who visited these sites, only to give the ever-repeated advice to the people around, that 'there is nothing to worry'. For them, these events were mere exercises to reassure the people. These were never considered as issues that were related to the Safety Profile of the reactors that they will building in the near future.

It is as recent as early 2001, a group of Geologists from the Department of Geology at the University College, Trivandrum who while guiding an MSc student for his dissertation on the geology of the Coast of the Kudankulam discovered the presence of a Dyke Swarm in the area[4]. They could identify about 14 carbonatite dykes, some of which were 300 meters long and 3 meters wide. This had made them postulate that this structure is a paleo-rift structure. The implications of such a finding is of immense importance to the Safety of the Kudankulam Nuclear Power Plant. The above statement means that this area has an unstable crust, with a fault that may be very deep in its throw.

The Nuclear Power Corporation of India Ltd., (NPCIL), the ATOMSTROYEXPORT and the Atomic Energy Regulatory Board (AERB) do not seem to be aware of the Safety Implications of all these events!

Again, the NPCIL or the ATOMSTROYEXPORT don't seem to be aware of this finding. The NPCIL says that it has conducted a micro-seismic study (that dates back to the year 1988), and that they have a nuclear plant which can withstand an earthquake of 6 Richters. They find solace in repeating their earlier statements namely: "this site has hard rock at reasonable depth providing good foundation conditions; the site is in Seismic Zone II which is associated with low seismic potential; there are no active faults in the vicinity[1]". All that might be fine! But it is strange, as to why the people incharge of constructing the largest nuclear plant of India, are simply not bothered about the most recent and the most strange Geological events of the area, that might one day prove dangerous to the very reactors they are building! It is keeping the possible disastrous implications of this negligence in mind, this book has been attempted.

Atomic Energy Regulatory Board (AERB) gave its clearence for the Project on 10 November,1989.[5] It states in the 'annexure' of this clearence that, "Site related design considerations such as seismic aspects etc. are to be established before submission of Preliminary Safety Analysis Report (PSAR). Design should be engineered to meet site related design basis events." It also states that "Bore-hole investigations are to be carried out at the proposed location of various buildings and structures. The report should be forwarded to design group for taking into account at the time of actual design."

From what we have said above, and from what we have presented in

the foollowing chapters of this book, we conclude that the ATOMSTROYEXPORT and the NPCIL could not have fulfilled this stipulation of the AERB. Instead, we postulate, they should have presented to the AERB that they have designed these Reactors taking into considerations, the data on the local earth tremors from the seismograph at Erwadi and the Bore-hole investigations they have conducted at the site.

This might look that the NPCIL has fulfilled the AERB's stipulations technically and legally; but that doesnot mean that it has considered all the important '...Site related design basis events'. In fact,the most important site related design basis event in this area is Rock Melt Extrusions (RME).

Rock Melt Extrusions were not known to have occurred in this area before 1998. This is the year in which the ATOMSTROYEXPORT started working on the DPR and the PSAR. However, the first studies on the RME of this area were published in a Geology Journal only in March, 2000; they both were based on the physical and microscopical observations of the extruded molten rock material. The third study appeared in the year 2001 and it had presented a chemical analysis of the extruded molten rock material. All the three studies were pointing out that this was a volcanic material, and that it had occurred in a specific set of NW-SE trending faultlines of the area. All the above studies had pointed out the immeadiate necessity to conduct further analysis of these events.

Incidentally, Kudankulam is located very near to one of the above fault lines; and from 1995 onwards, geologists have published articles in research journals about the presence of magmatic structures in the Kudankulam area itself. The most recent study of 2001,has found 14 parallelly occurring carbonatite dykes in the area, which means that this area has a faultline of a very deep throw.

The above studies give us a preliminary indication that the faultline over which Kudankulam is located is slowly getting activated. These studies lead us to arrive at an inference that, the preferred mode of neotectonism that these faultlines are exhibiting is 'Rock Melt Extrusions that are neither preceded or followed by earth tremors'. Can volcanic eruptions occur without any detectable earth tremors? Researchers answer to this question in the affirmative and the Science Page of '*The Hindu*' (dated 7 March 2002) have carried an article titled "Silent quake in volcanic region". It has cited two researches published in the recent edition of the Science Journal '*Nature*'.

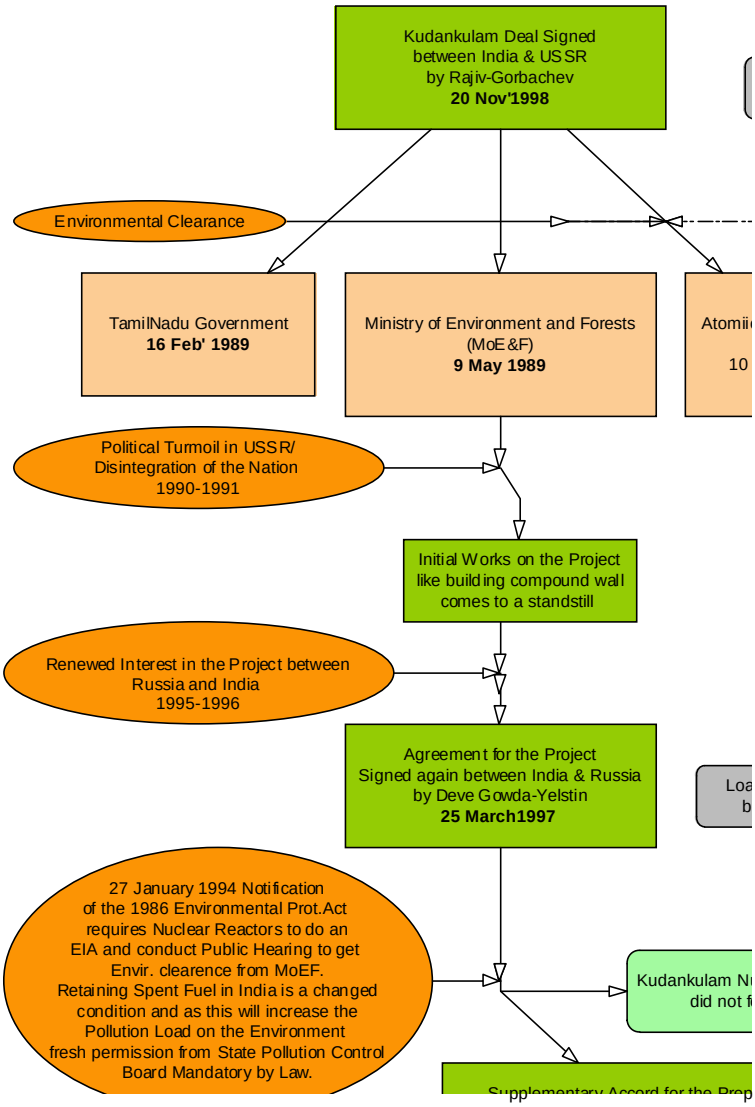
It is based on this finding, that the statement presented by the NPCIL that 'there are no active faults in the vicinity' seems us to be wrong.

We do not have the data on the date of completion and submission of the DPR and the PSAR to the AERB; but it was mandatory for the ATOMSTROYEXPORT to complete them within 24 months from the date of commmissioning the report. If this had been followed, then it should have been completed by May 2000 (as the commissioning date was 21 June 1998). Even if there might have been a delay by a few months , we feel it is quite possible that it would have been submitted to the AERB at least by the end of 2000. If that happens to be the situation, how is it possible that the PSAR of the DPR of this project could have considered all the above research studies (which of course are only preliminary ones on the issue)? If ATOMSTROYEXPORT was aware of the seriousness of these events and findings, instead of completing this report, shouldn't it have

If ATOMSTROYEXPORT was aware of the seriousness of these events and findings, instead of completing the PSAR, shouldn't it have asked the NPCIL to wait till the basic research on the mechanism of this phenomenon is presented by the Geologists?

We postulate that the AERB's stipulations on the 'site related engineering design' with respect to the Rock Melt Extrusions of this area, should not have been considered in the PSAR prepared by the ATOMSTROYEXPORT. This, we feel, will have very serious safety repercussions in the future, if not considered now.

Review of the Kudankulam Nuclear Power Project's Chronology*



* Based on the various References cited at the end of this Chapter.

asked the NPCIL to wait till the basic research on the mechanism of this phenomenon is presented by the Geologists?

Insteadd of doing this, ATOMSTROYEXPORT has completed the DPR and the PSAR for the project! It seems that the AERB is satisfied with this report and it seems it has given its clearance for the project!

However, we postulate that the AERB's stipulations on the 'site related engineering design' with respect to the Rock Melt Extrusions of this area, should not have been considered in the PSAR prepared by the ATOMSTROYEXPORT. This, we feel, will have very serious safety repercussions in the future, if not considered now.

We feel that the AERB should freeze the clearence it has given for this project at least temporarily, and review the site related design basis presented in the PSAR with the help of the research works on the rock melt extrusions and the occurrence of Carbonatite Dykes in this area.

This book presents most of the research works related to the abovesaid events.

As the author of this book is not a professional geologist (but a health professional!), this book is designed in such a way , that inferences are made only after the original works of the geologists are presented in full. Even though this might seem to be a long cumbersome process, this will certainly make the whole process of arriving at some conclusion or other a transparent one. Anyone going through the following pages will be free to refute the inferences of the author as the original research works are in front of them to make their own conclusions.

The AERB should freeze the clearence it has given for this project at least temporarily, and review the site related design basis presented in the PSAR with the help of the research works on the rock melt extrusions and the occurrence of Carbonatite Dykes in this area.

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5.Communication of Mr.S.K.Jain, Director of KK-LWR Project, NPCIL to Dr.N.Markandan dated 25 October 2001.

Introduction

The works related to the construction of the Kudankuam Nuclear Power Plant has commenced from October 2001. This NPP is at present planning to erect two light water nuclear reactors of 1000 MWe capacity. The actual concreting work for the first reactor is scheduled to start on March 31, 2002. These reactors are being purchased from Russia. The first reactor is expected to be commissioned in the year 2007 and the second in the year 2008. The spent fuel from these reactors will be stored at the site in the short and the interim term. There are also reports of a plan to build a Reprocessing Plant here, to reprocess this spent fuel in order to obtain Plutonium.[1]

The agreement for purchasing the above two reactors was signed originally on 20 November, 1988 between President Mr.Gorbachev of the erstwhile USSR and the then Prime Minister of India Mr.Rajiv Gandhi.[2] NPCIL, which is responsible for erecting these reactors, obtained the environmental clearance for the construction of these reactors from the Ministry of Environment and Forests, the TamilNadu Government, and the Atomic Energy Regulatory Board in the year 1989.

Two Light Water Reactors of 1000 MWe capacity each, are to be constructed at Kudankulam. They are being purchased from Russia. The first reactor will be commissioned in 2007, and the second one in the year 2008. The concreting work for the first reactor will commence on 31 March 2002.

The cost of these two reactors then was around Rs.6,000 Crores. USSR would provide the financial loan. The loan money could be paid back in Roubles.The Detailed Project Report (DPR) for the project, it was announced on the occasion, would commence in a few months time.USSR was to supply the fuel for the reactor [Low Enriched Uranium (LEU)] and was bound to take back the Spent Fuel (SF) from these Reactors.[3]

The MoE&F gave its clearance for the project on 9th May 1989. Tamil Nadu Government gave its clearance even a few months earlier... that is on 16 February, 1989. The AERB cleared this project on 10 November 1989.

The project, however, could not proceed further because of the political turmoil that the USSR faced in the following years. That country got disintegrated in the year 1991. The future of the Kudankulam project became bleak.

The newly formed Russian Government didn't show much interest in this project in its early years. It was then thought by every one that this project was once for all shelved.

However, in 1996, there were signals from Russia, that it was once again interested in reviving this project. Indian Government expressed its delight. USA in the early months of 1997, started putting pressures on the Russian Government to abandon this project. The Russian Government, however, withstood all these pressures.

This move culminated in a fresh agreement. The agreement was signed in New Delhi, by the Russian President Boris Yelstin and the Indian PM Deve Gowda. It was on March 25, 1997. Even though the agreement was once again for 2X1000 VVER-1000 nuclear reactors, it was basically different from the 1988 Gorbachev-Rajiv Agreement on four counts.

First, the estimated cost of the two reactors had gone up. It was said, then, that this might be Rs. 17,000 Crores (as against the original 1988 estimate of Rs.6,000 Crores). Second, the loan money should now be paid back, according to the new agreement, in American Dollars (and not in Roubles as envisaged earlier). Third, the erection part of the plant should

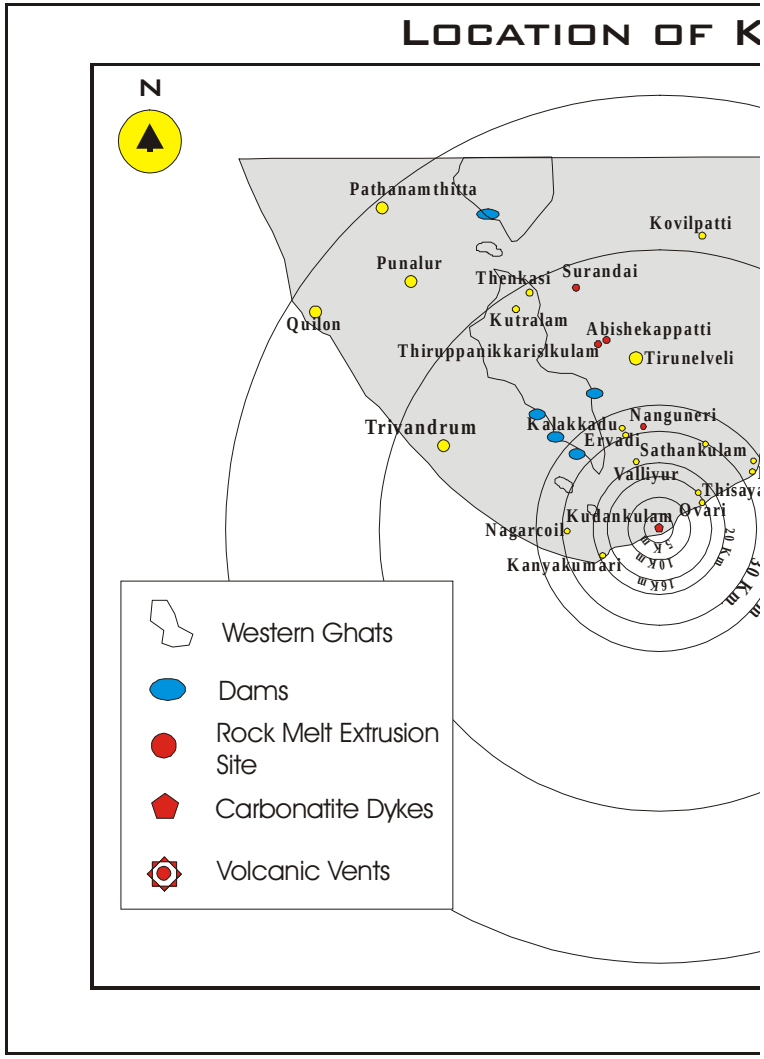

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Fig-1. Location of Kudankulam

The Director of MoE&F declared on 5 September, 2001 that the Environmental Clearance obtained for the Project is valid even today. She also declared that there is no need to conduct a public hearing for this project (made mandatory for such projects by the 1994 Notification of the Envir.Prot.Act) as this was cleared in 1989 itself, that is before the 1994 Notification was promulgated. However, her decision is in violation of certain clauses of the 1994 notification.

be undertaken by the Indian authorities themselves (and not by the Russian Engineers as decided in 1988. It ceased to be a turnkey project now in 1997). Four- the Spent Fuel coming out of the reactors, as per the 1997 Agreement, will not be taken back to Russia (as against the earlier 1988 agreement that it shall be transported back to Russia).

With these new amendments infused into the old Agreement of 1988, the project surged forward. On June 21, 1998, the Russian Atomic Energy Minister, Yevgeny Adamov, and Indian Atomic Energy Commission Chairman, R. Chidambaram signed a supplementary accord in Delhi for the preparation of the Detailed Project Report (DPR) (the cost of this report would be around Rs.250 Crores).So, this work on the DPR which should have commenced actually in the years 1989-90, began only in the year 1998, that is almost a decade after!

On July 4, 1998, an article in the magazine *Frontline* stated: "The [Nuclear Power Corporation] sources said that up to six reactors could be built at the site. The area where the first two reactors would come up had been identified and the Russians were satisfied with it." (*"Koodankulam is back" by T. S. Subramanian in issue dated July 4, 1998*).

On October 2000, Mr.Putin, President of Russia visited India. After visiting Bhabha Atomic Research Center (BARC) he stated, that Russia was prepared to give 4 more 1000 MWe VVER-1000 nuclear reactors to India.

The Director of NPCIL wrote to the Director of the MoE&F on 7 August,2001, [in which he had enclosed the communication from the Tamil Nadu Pollution Control Board (TNPCB) dated 21 June,2001] asking the Ministry for a fresh clearance for the project.[4]

It is due to this communication the present Director of the MoE&F Dr.Nalini Bhat visited the Kudankulam site on 31 August,2001; based on the observations she made during this visit, she declared on 5 September, 2001, that the environmental clearance issued on 9 May, 1989 still stood valid, and that there was no need to conduct a public hearing and there was no need to seek a fresh environmental clearance from her Ministry. (See appendix for a Critique of this decision).

Thus, the way for Kudankulam Project got cleared. It is time, that at least now, we ensure the safety of this Project.

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3. "A few truths about Kudankulam Atomic Power Project", *a booklet in Tamil by Nuclear Power Corporation, 1989.*
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1. The Problem

The event was long expected!

The Rock Melt Extrusion (here after let us call this phenomenon as RME) that occurred at a place near the Surandai town of the Thirunelveli district occurred on the early hours of 24 November 2001. There was much panic everywhere in the district during the following few days. It is not very hard to find out as to why the people were so panicked about such a trivial incident. Trivial it may seem, but it remains an unsolved geological mystery even today!

This is not the first time that such an incident is occurring in this district. Similar incidences have been occurring in this district almost every year over the past four years. They have generated a volley of explanations as to why such an event is occurring in the first place. We shall consider all of them in the following chapters and try to find out as to what might be the best explanation from a scientific view point of all these events.

1.1. The past four years

An RME (Rock Melt Extrusion) manifested itself on the night of 4 August 1998 in a Government Animal Farm near Thirunelveli. This farm is located in the Thirunelveli-Thenkasi state highway and is one kilometer east of the Manonmaniam Sundaranar University. A concrete electric post which was carrying a 220 Volts domestic electric line and standing near the vent of the event was melted completely in its lower half and had sunken into the ground. This place is about 60 kilometers (aerial distance) north-west of Kudankulam. The next day, on August 6, 1998, a similar event occurred at a place called Parappadi. This village is located at around 2 kilometers east of the Nanguneri Town of the Thirunelveli district. This place is about 32 kilometers north-west of Kudankulam. Both the events were widely reported by the press and the electronic media, and were the cause of much concern both among the people and the district authorities.

The next year, that is 1999, saw a similar RME at a place called Thiruppanikarisalkulam on September 29. This is a village near Thirunelveli and is about 60 kilometers north-west of Kudankulam.

In the year 2000, on February 26, a mild tremor shook Kalakkadu-Erwadi region of the district. This region is about 30-35 kilometers north-west of Kudankulam.

In 2001 January at a place called Maruthankulam of the same district, the land had cleaved to form a very large pit. This place is about 27 kilometers north-west of Kudankulam. There was no rock-melt in this event. The same month witnessed a mild tremor at the Mylanur-Kadayam region of the district. This region is about 60 kilometers northwest of Kudankulam. On February 25, the area around Thenkasi witnessed a mild tremor. This area is about 85 kilometers north-west of Kudankulam.

In the year 2001, we have the RME near Surandai on 24 November. This place is located at around 75 kilometers north-west of Kudankulam.

So, every year from 1998 onwards we are witnessing some geological event or the other in this district. Out of these events we note that the RME has occurred 4 times at places located at around 30 to 75 kilometers north-west of Kudankulam.

Geologists have reported the presence of two dormant volcanoes in the

Geologists have reported the presence of two dormant Volcanoes in the Sea Bed of the Gulf of Mannar. The vents of these Volcanoes are located at around 115-125 km south-east of Kudankulam.

Gulf of Mannar at about 130 kilometers south-east of Kudankulam[1].

To top all these findings, Geologists like Prof.M.Rama Sarma have postulated the Kudankulam area as a possible rift zone. Rifts are regions of low crustal stability.

Are the reactors that we shall be building at Kudankulam, designed to meet such a geological environment? Does the Preliminary design and Safety Analysis Report(PSAR) of the plant contain solutions to the threats and risks from such a geological locale? Have the Russians conducted a Probabilistic Safety Analysis for these reactors that shall give us an idea about the probability with which the abovesaid geological events shall damage the Core of the Reactor (PSA-1) and its Containment (PSA-2)[2]? What are the mitigatory measures they have incorporated into the construction and the design of these reactors to face the risks from the area's Geology?

Are the reactors that we shall be building at Kudankulam, designed to meet such a geological environment?

This book expects that the NPCIL should place all these documents in the open, and convince the people of the region and the state that all these issues have been taken care of and ensure that the design and the beyond-design solutions provided to mitigate the risks from the geology of the area are sound enough to protect everyone living around. In case the organisation has not conducted such a study, it should start doing such an analysis at least now. To do this, it should not even to hesitate to freeze the construction of the reactor that is about to start on March 31st; for, if it doesn't take this harder decision, how can it incorporate any design change in the reactor that the local Geology may warrant after an analysis?

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2. Research works pertaining to Rock Melts

2.1. Prof.G.Victor Rajamanickam and Dr.N.Chandrashekar[1]

Prof.Victor is the Head of the Department of Earth Sciences of Tamil University, Thanjavur. Dr.N.Chandarashekar is at the Department of Geology, V.O.C.College, Tuticorin. Let us now see their findings:

" On 5th August,1998 there was a report in the newspapers about the occurrence of rock extrusion at Abishekappatti, Trinelveli district, TamilNadu. The extrusion appeared at midnight on 4th August without any tremor or any other natural phenomena like heavy downpour or cyclone. The site of extrusion remained like a torch of red flame for nearly six hours. People could not reach the site due to extreme heat radiation which remained for more than a week. The villagers informed of this occurrence to the Science Centre at Trinelveli and the Geology Department of V.O.C.College,Tutiicorin.

Though some of the scientists attribute the incidence to the electric pole short circuiting, the extrusion is nearly a meter away from the high tension electric pole which itself was partly melted by heat radiation. The impact of the melting around the electric pole and concrete has made the pole sink to the ground by a few meters. The molten rock looks like black glassy volcanic mass with conchoidal fracture and pipe like cavities which extends to a depth of about 5 m. The surrounding quartzite has also been transformed into black coloured melt. Pyrite like golden flakes were found strewn around the pipe upto a radius of a few meters. Under the microscope, it is brown in colour and completely isotropic. It is identified as **obsidian.**

The extrusion has taken place along a major lineament in the direction of north-west to south-east as reported by many earlier workers. It is interesting to note that a similar extrusion has taken place at Parappadi village, Trinelveli district on 6th August, 1998 along the same lineament and that too in the vicinity of a pole of high tension power line. The material is more or less the same. However, the heat radiation is not to the extent of causing melting (of the electric pole). On 29th September, 1999, another rock melt extrusion appeared in Thiruppanikarisalkulam about 2KM west of Abishekappatti in the direction of Parappadi-Abishekappatti lineament. It is important to note that such activities are reported from a lineament zone along which a nuclear power plant is proposed to be established. Similar events have been reported in the Journal of Geological Soc.India, v.53, p.612 and v.54., p.552. In Purulia district also such repetition of rock melt extrusion has taken place in one year.

In view of such frequent reports recently from scientists and researchers, it is suggested that a concerted effort should be taken without any further delay by identifying a multi-disciplinary national team by the Ministry of Science and Technology to examine *inter alia* the following points:

1) Is such an event related to any high tension power transmission?

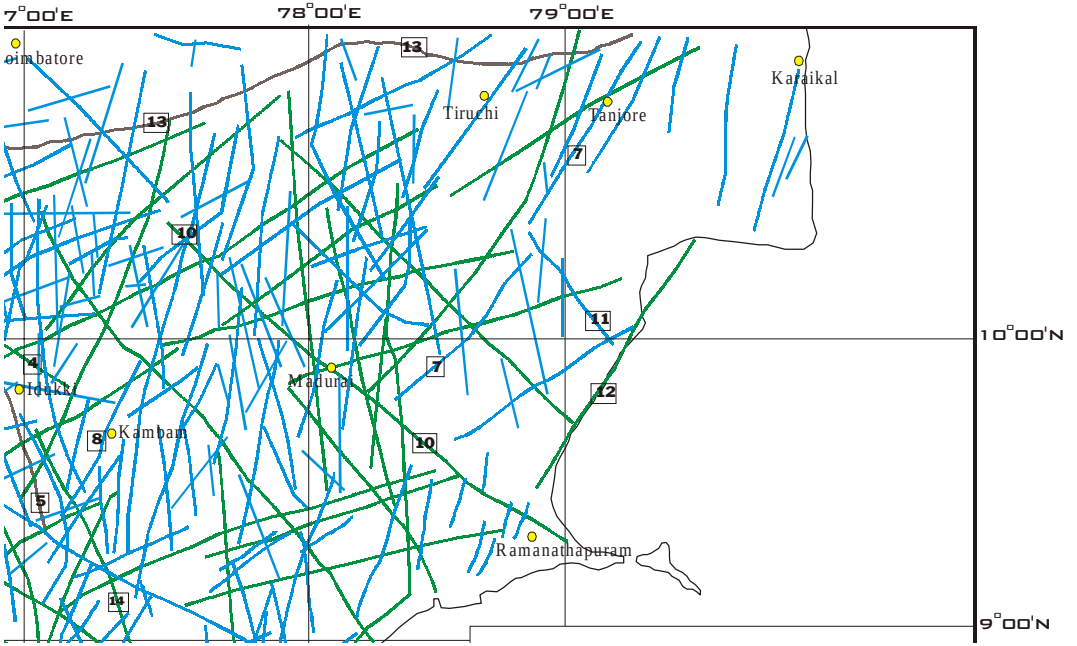
2) Is there indication of shear movement or other neotectonic activity?

3) Is it confined to a lineament plane?"

The Molten Rock Extrusions of Abishekappatti, located 60 km north-west of Kudankulam when analysed under microscope, was identified as Obsidian. Obsidian is something that is found only in the earth's Mantle. It is never a component of the Earth's Crust.

Is such an event related to any high tension power transmission? Is there indication of shear movement or other neotectonic activity? Is it confined to a lineament plane?

South of Palghat-Cauvery Shear



2.2. Dr.R.Ramasamy[2]

We shall now go through the research paper published by Dr.R.Ramasamy, who is a Geologist working in the TamilNadu State Department of Geology and Mining, Chennai.

"There have been several recent reports of rock melt extrusions in many parts of India, most of which have been attributed to leakage of electric current near the poles/pillars of high tension electric lines, causing subsurface melting of bedrock and soil. Recent incidences from Tamil Nadu show the following features:

1) Spitting of glassy fluid in the shape of cords and threads in Sirukinaru village near Kangayam on 5 June 1996 and spraying of beads 1cm to 1 mm diameter in Arakkonam on 24 June 1999 upto a distance of 50 meters from the vent.

2) Glassy material containing gaseous cavities or vesicles.

3) Soil in contact with viscous melt is baked at the contact for about 2 meters from the vent. The contact is charred, oxidised and hardened but not melted or fused.

4) Slow rising of temperature and slow cooling of rocky matter continued for 2 days in Abishekappatti near Tirunelveli on 6th August 1998, and for 12 hours in Thiruppanikarisalkulam near Thirunelveli on 29 September 1999.

5) No relics of fused quartz or feldspar are noticed, although xenocrysts of quartz with corroded boundaries but without isotopic rims are noticed. The rims are however bleached and fractured. Glassy material appears to have been injected into minute fractures in the grains. This feature is found in Thiruppanikarisalkulam.

6) High temperature euhedral phenocrysts of sanidine and leucite as well as phlogopite, sodalite and magnetite are seen in Sirukinaru. Skeletal crystals of plagioclase and clinopyroxene are seen in Arakkonam. The chemical composition of the melt, excluding the phenocrysts, is close to that of basalt.

7) Sprayed beads have caused scar pits by impact on the rock debris. High temperature aureoles and ashy rims were seen around the pits.

8) Melt from vent has sprayed on and clung to tree branches and burnt them.

9) There is no gradation between the host rock and the molten rock. Apparently the melting feature does not bottom out.

A huge amount of electrical energy is required to melt rocks and soils of a cu.m. volume below the ground level. TamilNadu Electricity Board had reported only two electricity trippings of 3 and 9 minutes from a 11 KVa power line, which is insufficient to cause the scale of melting noticed in Thiruppanikarisalkulam. *As an alternative explanation these incidences may be due to the rise of lava tubes resulting from the hitherto unknown subterranean volcanic activity in the region.*"

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These incidences may be due to the rise of lava tubes resulting from the hitherto unknown subterranean volcanic activity in the region.

2.3. Dr.G.Manimaran, Dr.P.Sivasubramanian, and Dr.M.Senthiappan [3]

Dr.G.Manimaran and Dr.P.Sivasubramanian are at the Geology Department of V.O.C.College, Tuticorin. Dr.M.Senthiappan is with the Geological Survey of India, Mangalore. Let us look into their research study

on this phenomenon now.

" Villagers of Abishekappatti village (E77^{0}39'18" and N8^{0}45'58"),10 km NW of Trinelveli town, TamilNadu, reported fire and smoke close to an electric (11KVa) concrete post in the early hours of 6th of August 1998. The villagers in the morning noticed that the concrete post had sunk upto a depth of 4 m. The villagers also reported fire and the effects of burning in the soil and vegetation in adjacent cracks near the electric post, in a particular direction. Similar such occurrences were reported from Anikulam(E77045'8" and N8^{0}26'11") during the first week of September, 1998 and from Pondichery village(E77^{0}45'58" and N8^{0}24'32") of Trinelveli district. On 29th of September,1999 another rock melt extrusion appeared at Thiruppanikarisalkulam(E77^{0}37'30" and N8^{0}45'00") near an electric post, 4km SW of Abishekappatti.

To understand the real cause for the phenomenon, the following possibilities are suggested (Jeyakaran,1998; Rajamanickam and Chandrashekar,2000 and R.Ramasamy 2000).

1) High-tension electrical leakage-related RME,

2) Lightning strikes-related super heating and instantaneous melting of the soil and rock causing fulgurite and glass formation,

3) Neotectonic activity.

Observations:

At Abishekappatti a detailed study was done through excavations. The country rock is quartzite with enclaves of garnet-biotitic-sillimanite gneisses (Khondalite) and is covered with one metre thick red soil. After removal of the topsoil, a small vent with a diameter of 25 cm size was seen near the electric post. When we opened the vent, it was lined with thin layer of black glass. One metre away from the post, the vent was completely concealed with black glass. The massive cylindrical shaped glass is encircled with four different layers from core region to rim. 1) 1-3 cm thick resinous water-bearing greyish green glass, 2) Green, fine grained vesicular rock zone of 4-10 cm thick, 3) Pyroxene-bearing calcic-plagioclase zone of 5-10 cm thick and 4) encircled on the rim by 4-10 cm thick recrrystallised quartz in contact with the outer zone of baked quartzite. The exposure can be traced even 7 m away from the post. The clustered golden coloured vermiculite flakes after biotite were found at the contact of Khondalites and baked quartzite, possibly due to extreme heating. Apart from this main vent, upward branching tiny vents of 1-5 cm size (similar to fulgurites) are observed in the adjoining country rock.

Petrography and Petrochemistry:

Under microscope, the black glass is brown, non-pleochroic and isotropic. At places, vitrophyric with augite and hypersthene phenocrysts. The adhered xenocrysts of quartz and rutile are from the country rock. The resinous greyish green glass is identified as palagonite (H_2O bearing tachylite). The green coloured rock shows microliths of pyroxene, euhedral magnetite, chlorite, serpentine, quartz and brown glass. Silimanite and cordierite also occur as xenocrysts.

Representative samples of black glass, associated green coloured rock and quartzite, collected 5 m away from the concrete post, were analysed at Marine Wing Lab, G.S.I., Mangalore. SiO_2 was estimated by standard wet chemical method. Major annd minor elements were determined by

Rock Melt Extrusion samples from Abishekappatti were analysed at the Marine Wing Lab, G.S.I., Mangalore.

The samples were found to be basic in composition with high content of Cr and Ni. Petrochemiclly the green, vesicular glassy rock is compositionally similar to subalkaline tholeiitic basalt.

Atomic Absorption Spectrometer (AAS). B2283/INHOUSE GSI standards were used. The precision is about 1 to 2%.... The samples are basic in composition with high content of Cr and Ni. Petrochemiclly the green, vesicular glassy rock is compositionally similar to subalkaline tholeiitic basalt.

Conclusions:

Microseismic activity is well known along the lineaments bounding the different tectonic units in peninsular India. The WNW-ESE striking Achankovil-Thambraparani Shear (ATS) lineament and NW-SE striking dextral Tenmalai-Gatana Shear (TGS) lineament of South India extends through the Abishekappatti-Thruppanikarislkulam and Anikulam-Pondichery village respectively.

Similar extruded materials at Anaikulam, Pondichery village and Thiruppanikarislkulam and recent mild tremor on 26th February,2000 at Kalakkad and Erwadi of Trinelveli district may lead to the speculation indicating the reactivation of ATS and TGS lineaments. However, the close proximity of the molten rock material occurs always near to the electrical installations and since these factors are not traced much beyond the surface, to the deeper parts, so the tectonic linkage is premature."

2.4. Dr.G.Victor Rajamanickam (2002)[4]

Samples of RME were collected by volunteers from Surandai-Anaikulam area (extrusion date: 24-11-2001) and the Animal Farm at Abishekappatti (extrusion date: 05-08-1998) on 01 March 2002. They were submitted for a detailed analysis to the Department of Earth Sciences at the Tamil University on 05 March 2002 by Dr.N.Markandan, former Vice-Chancellor of the Gandhigram Rural University. The result of the analysis is given below:

Rock Melt Extrusion Samples from Abishekappatti and Surandai were analysed.

"To:

05/03/2002

Dr.N.Markandan,
Former Vice-Chancellor,
Gandhigram Rural University.

Respected Professor,

The materials of the melt extrusion taken place on 24-11-2001 and on 05-08-1998 from Surandai-Anaikulam and the Animal Farm-Abishekappatti respectively, have been scanned and studied in this department. These materials are of glassy in nature containing sufficient gaseous cavities and vesicles. They also indicated evidences for getting charred. The material shows the presence of typical characters pertained to volcanic rock. Some of the phenocrysts suggest the presence of sanidine, leucite, mica and opaques. The specimen indicated the presence of volcanic beads of varying size including coalesced ones. It does not show any evidences of relation to host rocks. In certain species provided scar pits formed by the impacts. Charred dark circular patches are seen in some parts of the specimen.

The specimen indicated the presence of volcanic beads of varying size including coalesced ones.

The xenocrysts are vitrophyric in nature with quartz, augite and hy-

The chemical analysis of this glassy material is scanned with high rate of chromium and nickel. It is the typical indicator of basic nature of composition. The silica in the glass also confirms its volcanic nature.

persthene in the glass. Palagonite presence is also noticed. The chemical analysis of this glassy material is scanned with high rate of chromium and nickel. It is the typical indicator of basic nature of composition. The silica in the glass also confirms its volcanic nature.

Samples from Surandai[5]

Samples from Abishekappatti[5]

Under such circumstances, it is a must before going for any major structure in Kudankulam, one has to ensure the tectonics of this block.
It is lying on a lineament plane. So, it is a must to take up micro-level studies for confirming the tectonic stability of this landmass in the region before launching a major plant in Kudankulam.

The reconnaissance of geomorphological and geological studies have indicated the presence of lineaments in this region. Between Kanyakumari and Mandapam, the entire region is controlled by the major east-west lineaments which divide the region into 5 different east-west blocks. These

blocks behave independently and they tilt along the strike slip and develop the movement in these lineaments. When such is the tectonic structure of this area, the rock melt injections in Abishekappatty, Thiruppanikarislkulam and Surandai-Anaikulam are confirming the activities of neo-tectonic movements.

Over and above, the seismic tremors, tectonics in this region is also bringing a question of stability for the area. Large scale studies have already brought forward for Achankovil shear zone's role in de-stabilising this block. Under such circumstances, it is a must before going for any major structure in Kudankulam, one has to ensure the tectonics of this block. It is lying on a lineament plane. So, it is a must to take up micro-level studies for confirming the tectonic stability of this landmass in the region before launching a major plant in Kudankulam.

Thanking You,

Your's sincerely,

/signed

(G.Victor Rajamanickam).
Dean - Science Faculty,
Sr.Professor and Head,
Dept.. Of Industries and Earth Sciences,
Principal Investigator for DST,DOD,CSIR,INSA,GMC,UGC,
Tamil University, Thanjavur - 613 005"

2.4. G.R.K.Murty, Y.Satyanarayana and T.Pradeep Kumar[6]

The above researchers have studied the Magnetic Profile across Gulf of Mannar. They work in the Naval Physical and Oceanographic Laboratory, Thrikkakara, Cochin. Let us now go through their work:

" The Mannar depression is one of the three depressions of the Indo-Ceylon trough occupying the south-eastern part of the Indian peninsula. ... Geologically the depression in the Gulf of Mannar has an important significance because of its location and structural prospects... This paper attempts to analyse the magnetic and bathymetric data collected along a profile AA'(Fig-1) in the year 1986, of about 200 km length across southern part of the Mannar Gulf.

Volcanoes with underwater summits were also reported in this area . This suggests the presence of volcanic vents in the area.

According to Eremenko and Gagelganz (1966), the Indo-Ceylon trough / Gulf of Mannar is considered to belong to the Mesozoic-Cenozoic (245-5.5 million years) group of basins. The regional alignment of tectonic features is NE-SW, parallel to the Eastern Ghat trend. They have opined that the basement has a horst-graben configuration resulting from faults with considerable throw.... Kumar(1983) has reported the presence of basaltic rocks from the borehole drilled in the northern part of the Mannar depression.

The two dimensional model under the constraint of spectral depth shows the presence of an anomalous body (180 km long) within the basement... The reported volcanic vents in the vicinity suggest the possibility of the anomalous body and volcanic vents in vicinity may togather indicate the presence of a major tectonic structural feature in the Gulf of Mannar.

... The spectral analysis of the marine magnetic data along AA' across the Gulf of Mannar reveals two depths at about 4 and 9 km from the sea surface. The two dimensional model under the constraint of spectral depth shows the presence of an anomalous body within the basement.....This two-dimensional model..suggests that this anomaly may be basic in nature, having a length of about 180 kilometers. The depth to the top of the body varies from 5 to 11 km from the sea surface with a regional relief, of about 6 km. This relief coincides with a broad gravity low. The reported volcanic vents in the vicinity suggest the possibility of the anomalous body and volcanic vents in vicinity may together indicate the presence of a major tectonic structural feature in the Gulf of Mannar.

...W.S.Carl (in [1966] Seismicity of the Indian Ocean, J.Geophy.Res. v.71,pp.2575-2581) has reported a shallow earthquake (location shown in Fig.-1) of magnitude less than 7, very close to AA'. The location of the epicenter of this earthquake lies over the northward extension of the fractures trending in N-S direction. Volcanoes with underwater summits were also reported (Udintsev,G.B.[1975] Geological and Geophysical Atlas of the Indian Ocean, Moscow, Academy of Sciences, 151p; Sastri,V.V., Venkatachala,B.S., and Narayan,V., [1981], The evolution of East Coast India. Paleogeogr. Palaeoclim.Paleoeco., pp.366 23-54) in this area and are shown in Fig.1. This suggests the presence of volcanic vents in the area. So, the anomalous body inferred from magnetics could be related to such volcanic vents. The high susceptibility value of 0.02 cgs suggests that the body could be more basic in nature."

2.5. Dr.Biju Longhinos and Prof.M.Rama Sarma[7]

Dr.Biju Longhinos is a Lecturer in the Department of Geology, University College,Trivandrum. Prof.M.Rama Sarma is a retired Geologist. These researchers have studied the Seismo-Tectonic signatures of the Kudankulam area. Let us go through their work now.

"A few earlier investigators have studied the outcrops of Kudankulam ($8^0$8'N-$8^0$11'N and $77^0$36'E-$77^0$45'E).[**Ramasamy.R** (1993), Occurrence of Olivine Tephrite and Carbonate Tephrite in Kudankulam area, near CapeComerin, TamilNadu in *Jour.Geol.So.India, V.45,331-333*; (1995), The evidence of Late Cenozoic volcano tectonic deformations in Kudankulam area, near CapeComerin, TamilNadu, *IGCP Rept., on Coastal Evolution in Quartenery Workshop, Proc.Abst,18-20*; **Shahin,M.G.**, (2001) Coastal Ridge and Dyke Swarm in Radhapuram Taluk, Tirunelveli, TamilNadu-A Geological Appraisal (M.Sc., dissertation, Unpublished)]. They have noted that the fossiliferous limestone lying over the country rock of this area are intruded by a different sequence of magmatic rocks. Magmatic intrusions are an indicator of a crust abiding deep fracture.(Figure-2 shows such crust abiding deep fractures elsewhere in India). Fractures give rise to magmatic processes and activate them. From the upper mantle of the earth, magmas of high density and fluidity rise and either consolidates in the fractures or pours out, as the case may be.

A few earlier investigators have studied the outcrops of Kudankulam. They have noted that the fossiliferous limestone lying over the country rock of this area are intruded by a different sequence of magmatic rocks. Magmatic intrusions are an indicator of a crust abiding deep fracture.

"The zones of deep fractures are the regions of crustal instability where seismic activities are concentrated.The major seismic zones on the earth surface are overlapped with the regions of lower crustal stability. Rift Valleys, a region with deep fractures,represent continental breaking, with sufficient seismic activity. These valleys have typical rock assemblages. **Kudankulam area has one such paleo rift structure.**The probable seismo-tectonic implications due to the presence of this structure, are deduced in this paper, from similar associations in the Rift Valley of East Africa.

Geological Setting:

The trend of the coast at Kudankulam is nearly East-West with a ridge of 54m high paralleling it. The ridge has a gentle slope towards North while steeps down to the coast, producing an escarpment like landscape. Five dry channels, which show radial drainage pattern with mouths at two to three meters above mean sea level, incise the ridge. They bear water at their mouths during high tides. A road, cutting the ridge, is paved to reach down to the shore. The intrusive rocks reported here are exposed only along the cuttings of the nullas and the road.

Rift Valleys, a region with deep fractures,represent continental breaking, with sufficient seismic activity. These valleys have typical rock assemblages. Kudankulam area has one such paleo rift structure.

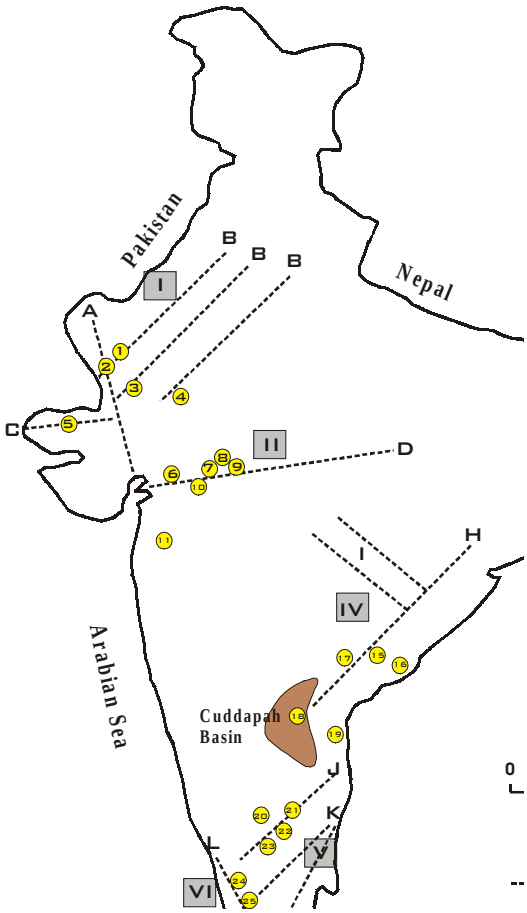
The ridge is made up of fossiliferous limestone. These rocks are correlated with Jaffna limestone and ages about 30 million years. The high-grade limestone of the Kudankulam is superfine for end uses in cement and steel industries. Presently India Cements are mining it.

Towards the north of the ridge the land is covered by highly fine red soil having a thickness of more than 5 meters. At places, the common country rocks form mounds on the surface.

Lithology:

Field observations indicate a lithological heterogenecity, especially along the ridge and down south. Charnokite, a rock produced at high pressure and temperature and common throughout South India, is associ-

Major Tectonic Structures and Related Car



ated with Carbonatite and Basalt, products of magmatic cooling. Carbonatites, rich in igneous carbonates, occur as patches, while Basalt cuts the Charnokite as dykes.

During the field study fourteen dykes were discovered. The rough parallelism exhibited by these dykes designate them as a swarm. The thickness of these dykes varies from a few centimeters to as much as three meters. A dyke has been traced for a length of two hundred meters.

Structure:

Structures are the resultant strain produced in a rock that undergoes one or more phases of stress. The primary structures of emplacement are exhibited by the intrusives, while the country rock show only secondary ones. This is a clear indication of a post-metamorphic intrusion.

The foliation of the country rock has a general trend, striking $N120^0$ and dipping 30^0 towards Northeast. In many outcrops the trend of foliation is not clear, due to thorough fractures/joints. Major joints that cut the region are given in Table.1.

Table.1.
List of major joints, their strike and dip

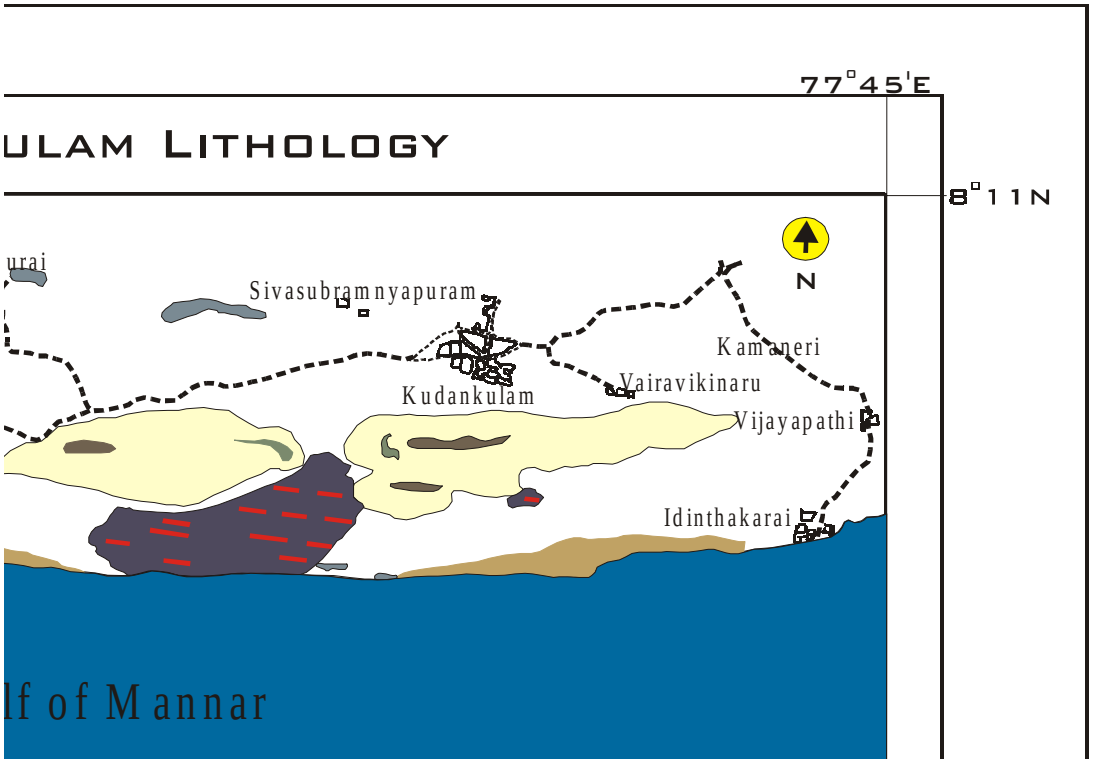
No	Strike	Dip
1	N 180^0	Vertical
2	N 0^0	60^0 N 160^0
3	N 90^0	Vertical
4	N 20^0	15^0 N 105^0
5	N 140^0	Vertical
6	N 160^0	Vertical
7	N 300^0	60^0 N 160^0
8	N 220^0	20^0 N 310^0
9	N 50^0	20^0 N 310^0

The joints striking N 180^0 and $N90^0$ with vertical dip are the master joints.They are closely associated with the intrusions of dykes. Table.2. gives the trend of dykes exposed in the nulla and road cuttings.

The fractures can be linked with the dykes in many ways. Some are pre-injection, some are syn-injection and some are post-injection of the magma. The older fractures would be confined to limited area into which the magma quietly wells up, while the syn-injection fractures are extension fractures opened up by tensional forces exerted by the magma reservoir and that it may propagate itself very rapidly, filled with dykes forming a swarm. Usually such dykes occupy fractures that form perpendicular to the least principal stress axis. The major joints of Kudankulam are syn-injection of the magma along a lineament, resulting in a dyke swarm.

A.Phillipots (in 'Introduction to Igneous and Metamorphic Petrology', Prentice Hall, New Jersy-1990), from field evidences, suggest using

During the field study of Kudankulam area, fourteen dykes were discovered. The rough parallelism exhibited by these dykes designate them as a swarm. The thickness of these dykes varies from a few centimeters to as much as three meters. A dyke has been traced for a length of two hundred meters.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mafic dyke swarms as indicators of rifts (both live and aborted). When a magmatic plume lance into the crust, the continental crust stretches beyond its limits developing tension cracks on the surface of the Earth. Magma rises and squeezes through these widening cracks,, sometimes to erupt and form volcanoes, if the rising column of the magma is voluminous ar else forms hypabyssal intrusives within the cracks. The rising magma, whether or not it erupts, puts more pressure on the crust to produce additional fractures and ultimately, a rift zone.

A three-armed graben centred on a domal uplift is produced on the surface of the earth during the plume upwell. One or two of them may die off in the course of the development of the rift. Such tectonic abortions are aulocogens (means "born as a furrow"), and are characterised by the presence of Carbonatite suite of rocks as well as Alkaline plutons.

Table.2.
The trend of the dykes of Kudankulam

Dyke	Strike	Dip with direction
1	85°	75° due south
2	80°	75° due south
3	90°	80° due south
4	90°	85° due south
5	90°	80° due south
6	90°	85° due south
7	90°	85° due south
8	90°	Vertical
9	90°	Vertical
10	90°	Vertical
11	90°	Vertical
12	90°	Vertical
13	90°	Vertical
14	90°	Vertical

Seismic Puzzle:

The rock association and the geomorphology of the coast of Kudankulam village give an aulcogen type of tectonic environment. It is more or less comparable to the petrology and structural association along the East African Rift Zone, which is seismically active.

... A moderate seismic activity (of magnitude ~ 4 in Richter scale) is reported from the East African Rift Valley. These quakes are more frequent in regions exhibiting volcanism. At the time of eruption of Oldinyo Lengai Carbonatite volcano in 1960, a high magnitude earthquake of 7R was recorded in Tanzania, which is situated in the rift Zone. The energy source of tectonic earthquakes is the potential energy stored in the crustal rocks during a long growth of strain. Beyond the competence of the rock, that undergo stress out of a magmatic injection, fractures develop and the energy is dissipated as earthquakes with relative crustal movements.

The rock association and the geomorphology of the coast of Kudankulam village give an aulcogen type of tectonic environment. It is more or less comparable to the petrology and structural association along the East African Rift Zone, which is seismically active.

Conclusions:

Nearly all Carbonatite occurrences are associated with grabens, aulcogens and lineaments of tectonic activity. Based on the studies of East African Rift Valley, dyke swarms are related to rifts spatially, that it forms right angle to the major rifting. Carbonatites and Basic dyke swarms are in close association at Kudankulam. In geological dialect the association indicates a rift. The drainage pattern and the escarpment along the Kudankulam coast substantiate the above statement.

Rifts are regions of low crustal stability. Like volcanoes, these faults may remain dormant for longer duration. As no severe quakes were reported from Kudankulam, we could confirm dormancy to the rifts of Kudankulam. Or else an aulcogen. A specific seismic monitoring is a must to predict the stability of the region today. For lack of seismic data, we restrain ourselves from any kind of prophecy."

Discussion:

The nature of Rock Melt material:

In the preceding pages, we have gone through four works dealing with the Rock Melt Extrusions that have occurred over the past four years in this region. Out of these four works, the one by Dr.R.Ramasamy is based on physical observation of the events and their products. Prof.Victor Rajamanickam and Dr.N.Chandrasekar (2000) have described the products of the Abishekappatti RME, as they have seen them under the microscope. Dr.G.Manimaran, Dr.P.Sivasubramanian and Dr.M.Senthiappan have given the results of chemical analysis of the products of Abishekappatti RME. Prof.Victor Rajamanickam (2002) has made a physical description of the products of the Surandai-Anaikulam RME, and the Abishekappatti RME; he has also given in his paper, the results of spectroscopic and chemical analysis of the products of the above two RMEs.The two chemical analyses that have been done so far, have been done in two different labs namely, the Marine Wing Lab of the Geological Survey of India located at Mangalore and the lab at the Department of Earth Sciences at the Tamil University, Thanjavur.

The above researchers have made varied conclusions. Prof.G.Victor Rajamanickam and Dr.N.Chandrasekar (2000), and Prof.Victor Rajamanickam (2002) have come to the conclusion that these products of the various RMEs are volcanic in their nature. They have suggested that these RMEs might be the manifestation of the neo-tectonics of this region. Dr.R.Ramasamy has made a cause-effect analysis of the 1998 Thiruppanikkarisalkulam event in which he analyses the role of electricity discharge from the transmission lines in bringing about this event. He has noted that there were two trippings of 3 and 9 minutes from a 11 KVa powerline and has concluded that the possible amount of electrical discharge from the above two trippings is insufficient to cause the scale of melting noticed in Thiruppanikarisalkulam. He has suggested that these events may be due to the rise of lava tubes resulting from the hitherto unknown subterranean volcanic activity in the region. Dr.G.Manimaran et al., are not so sure that these events are linked to the tectonics of this area.

They conclude, '... the close proximity of the molten rock material occurs always near to the electrical installations and since these factors are not traced much beyond the surface, to the deeper parts, so the tectonic linkage is premature'.

The Microscopic analysis of the Pyrite like golden flakes that were strewn around the vent of Abishekappatti by Prof.Rajamanickam et al.,(2000) have pointed out that they are Obsidian. Obsidian is never a part of the earth's crust, but is always a component of the Mantle.

This material is volcanic in its nature. The events that extrude this material always occur near electrical posts. They are also occurring in the known lineament lines. What might be the relationship between these three observations?

The results of the two chemical analyses conducted at two different labs have said that this material is basic in nature, and has a high content of Chromium and Nickel. This means that this material belongs to the mantle and not to the crust. Hence this material is volcanic in its nature. It is a little strange, as to why Dr.G.Manimaran et.al., who presented this evidence in their report, have rather failed to make this inference. They had been swayed by the fact that electrical posts were present near such events always. This association should of course be explained, no doubt, but why they failed to note the fact that their chemical analysis has clearly indicated that this material does not belong to the crust, but to the mantle, is what seems strange to us. The question, they should have formulated instead, in their research article should have been something like this: 'This material is volcanic in its nature. The events that extrude this material always occur near electrical posts. They are also occurring in the known lineament lines. What might be the relationship between these three observations?' Prof.Rajamanickam's chemical analysis of the extruded material from Surandai-Anaikulam area has once again confirmed the volcanic nature of this material. Hence, formulating a question similar to the one above, is the only scientific step that is left to us at present.

Electrical Posts and Rock Melts:

Can the rocks be melted by electrical discharge from transmission lines? Let us try to answer this question now.

To melt the rocks, they should at least be heated to about 800^0-1200^0C. To melt about 1 Kg of rock that is placed in a special Crucible, we will require 900 Kilo Joules of energy. Is it possible, for the transmission lines near RMEs to have discharged such a large amount of energy before the occurrences of the RMEs in these places?

To answer this question, we shall first of all look into the preconditions for melting rocks into lava. To our query in the internet, we came across an article titled, 'How to make lava at home?' posted at http://home.earthlink.net/~jimlux/lava.htm. The article is by one Mr.Jim Lux.[8] It tells us that to melt the rocks, they should at least be heated to about 800^0-1200^0C. To melt about 1 Kg of rock that is placed in a special Crucible, we will require 900 Kilo Joules of energy.

Now, the question is, is the same amount of energy enough to melt rocks when they are present in their natural locale state? No.Certainly this will require a lot more energy than for melting a rock that is placed in a crucible. Is it possible, for the transmission lines at Abishekappatti, Thiruppanikarisalkulam, Parappadi and Surandai to have discharged such a large amount of energy before the occurrence of the RMEs in these places?

Interviews with the witnesses of these events generally revealed that these transmission lines were intact when the RMEs took place. They also said that these events were not preceded by any heavy downpour or Lightning. However, at Pondicherry village near Parapppadi, some of the respondents said that there was a downpour with lightnings before the oc-

currence of the RME in that village.

Even in the hypothetical situation of the electrical lines falling over the ground, such an event can not happen. The ground will resist the electrical discharge, and this might lead the land to burst but not melt to the extent seen in the abovesaid events. Also, when the transmission line falls over the ground the whole electrical network will trip. If it does not trip, then the turbines in the electricity generating stations will be forced to rotate in the opposite direction, thus leading to a largescale damage in the electricity generating stations.

We are finding it increasingly difficult to explain the proximity of electrical lines and Rock Melt Extrusions using the present day scientific notions. However their close proximity is an established fact. At the same time, the volcanic nature of the extruded molten rock is also an established fact. How do these two go togather?

We are finding it increasingly difficult to explain the proximity of electrical lines and Rock Melt Extrusions using the present day scientific notions. However their close proximity is an established fact. At the same time, the volcanic nature of the extruded molten rocks is also an established fact. How do these two go togather?

Fault Lines and Rock Melt Extrusions:

When we analyse location of the places where the RMEs have occurred so far, using the map showing the Fault lines south of the Palghat-Cauvery Shear as presented by G.Manimaran et al., [which again is based on Ramachandran (1991)], certain interesting points emerge.

The first point we note in the map is that all these places are located close to three lineaments. They are Achankovil -Tamiraparani Shear, Thenmalai-Gatana Shear and the Thoranamalai Shear. All of them are NW-SE trending lineaments.

We see Kudankulam located in between the Thoranamalai Shear and the Cheranmahadevi-Kanyakumari Fault. We also see that the Thoranamalai Shear located just 3-10 km north-east of Kudankulam.

We note from the map, that all the above three lineaments are close to each almost intricately related.

The questions that arise in our mind now is this:

'Why are these Rock Melt Extrusions occurring repeatedly in this group of lineaments? What are the favourable factors that make the Rock Melt Extrusions possible here?'

'Is it possible for such a rock melt extrusion to occur at Kudankulam, as this place is almost located on the Thoranamalai Shear?'

The places where the rock melt extrusions have occurred are all located close to a set of three interrelated, NW-SE trending lineaments. They are the Achankovil lineament, Thenmalai-Gatana Shear and the Thoranamalai Shear. Kudankulam is located very close to the Thoranamalai Shear.

Volcanoes:

G.R.K.Murty et.al., have reported the presence of volcanic vents in the Gulf of Mannar. They have also cited two references that have reported the same feature earlier. From the map that G.R.K.Murty et.al., have provided in their paper, we come to know that these volcanic vents should be somewhere between 115 to 125 KM south-east of the Kudankulam site.The volcanic vent is associated with the presence of an anomalous body of 180 kilometers length, within the crust and this body may be basic in its nature. The epicenter of the earthquake in 1966 (reported in Carl,W.S., (1966) Seismicity of the Indian Ocean, J.Geophys.Res. v. 71, pp.2575-2581), of a magnitude <7 is located at around 190 KM south-east of the Kudankulam site. The location of the epicenter of this earthquake lies over the northward extension of the fractures trending in N-S direction. However, the regional alignment of the tectonic features is

NE-SW, parallel to the Eastern Ghats trend. Gulf of Mannar is considered to belong to the Mesozoic-Cenozoic group of basins.

Carbonatite Dykes at Kudankulam:

Prof.M.Rama Sarma and Dr.Biju Longhinos have identified 14 carbonatite dykes that are lying parallel to each other at Kudankulam.The rough parallelism exhibited by these dykes indicate that they are Swarms.

These dykes are a few centimeters to as much as 3 meters thick. One of the dykes has been traced for a length of 200 meters.

This is the first rime that Geologists have identified dykes in the Kudankulam area. This field research was conducted in the early 2001 and the results are yet to be published.

What this means to us is that, at some time in the Geological past, Magma has intruded the Crust of Kudankulam, which when got cooled down later, formed the abovesaid dykes. Magmatic intrusions are an indicator of a crust abiding Deep Fracture.

The zones of deep fractures are the regions of crustal instability where seismic activities are concentrated. The major seismic zones on the earth surface are overlapped with regions of lower crustal stability. Rift Valleys, a region with deep fractures, represent continental breaking, with sufficient seismic activity. These valleys have typical rock assemblages. Kudankulam area has one such paleo rift structure. It resembles the structure of the Rift Valley of East Africa which is seismically an active zone. A volcano named Oldinyo Lengai is situated in this zone. It is a Carbonatite volcano. It erupted in the year 1960. At the time of this eruption, a high magnitude earth quake of 7R was recorded in Tanzania which again is situated in the rift zone.

Even though no severe earth quakes have been reported in the Kudankulam area, the seismo-tectonic implications of this rift structure should be borne in mind and a specific seismic monitoring plan should be instituted to predict the stability of the region today is the conclusion that Prof.Rama Sarma et.al., have provided at the end of their research paper.

Certain Conclusions , some Questions and a few useful informations:

Conclusions:

1. We have an area stretching to about 80 KM north-west and 150 KM east-south-east of the Kudankulam site exhibiting volcanic materials. Incidentally Kudankulam site itself exhibits materials which have flown from the mantle.

2. Out of these places in which volcanic materials are found, the materials found in the places located with in 80 kilometers northwest of Kudankulam is of very recent origin (Four and less than four years old). The anomalous body detected at around 125 kilometers southeast of Kudankulam in the Gulf of Mannar oceanfloor might belong to the Mesozoic-Cenozoic era. The Carbonatite dykes of the Kudankulam area are yet to be dated; but it wouldn't be wrong if we state that they are not of recent origin. They also mean that there is a fault of a deep throw at Kudankulam.

3. The occurrence of the volcanic material in the recent past, is al-

What all the above observations mean is this: this area which was subjected to volcanism in the earlier Geological ages, has started exhibiting the same in the present Geological era too. In other words, we must state that this area is witnessing Neo-Tectonism.The preferred mode in which this Neo-Tectonism is exhibited over the past few years seems to be through Extrusions of Rock Melts from the Mantle, along a set of three NW-SE trending lineaments, and this is neither preceded nor succeeded by earth tremors. It also prefers to exhibit itself near electric posts.

ways near a group of three inter-related northwest-southeast trending lineaments. Incidentally it is in a place located over the Thoranamalai Shear (that is Kudankulam) geologists Biju and Rama Sarma have identified the presence of Carbonatite Dykes. What this means is that, this lineament, which was active in a particular earlier geological age, is showing signs of activity now.

4. What all the above observations mean is this: this area which was subjected to volcanism in the earlier Geological ages, has started exhibiting the same in the present Geological era too. In other words, we must state that this area is witnessing Neo-Tectonism. The preferred mode in which this Neo-Tectonism is exhibited over the past few years seems to be through Extrusions of Rock Melts from the Mantle,along a set of three NW-SE trending lineaments, and this is neither preceded nor succeeded by earth tremors. It also prefers to exhibit itself near electric posts.

Questions:

1. Why were these rock melt extrusions not preceded or succeeded by earth tremors?

2. Why was the 26th February 2000 earth quake of Kalakkadu not followed by any rock melt extrusion in this area? Why didn't we see any RME that year? Is the occurrence of this earthquake anything to do with the non-occurrence of RME that year?

3. Even though the Rock Melts have now been proved to be coming from the Mantle, why were their vents not tracable beyond a few meters? Also, what might be the reason for these events to occur always near the electrical posts?

4. Why is it that only this set of three NW-SE trending lineaments affected? Why is it that the Kudankulam area has not been affected by this phenomenon till today, even though it exhibits carbonatite dykes which means that the area should be having a crustal fracture with a deep throw?

5. Is there any possibility for the Gulf of Mannar's oceanic crust to be experiencing a similar phenomenon? We can not know the answer to this question, as we do not have any systematic research program to observe this there.

Informations that might be useful in finding answers to the above Questions:

1. Earthquakes:

Earth tremors have occurred at about 150 to 200 KM from Kudankulam in the Gulf of Mannar in 1938 (10th September/ 5.8 (IMD)/ 07.50N, 79.00 E)[9], 1966 [<7 (Carl., quoted from G.R.K.Murty et al.,)], and 1993 (6 December/Mb 5.2, Ms 4.7/20:54:45.43 UTC/ 06.818N, 78.301E, 10kms depth/Felt in Colombo, Sri Lanka)[9].

Similarly, tremors have occurred at Nagarcoil in the year 1823 [9th February/ (H.N.Singh et al.,)[10]/ ? intensity], at Nanguneri in 1881 [16th March/3R/(USGS- 'zirbes@usgs.gov')], at Kalakkadu-Ervadi in 2000 [26 February/3R/(*Dinamani*,2 March,2000)].

2.Geology of the area:

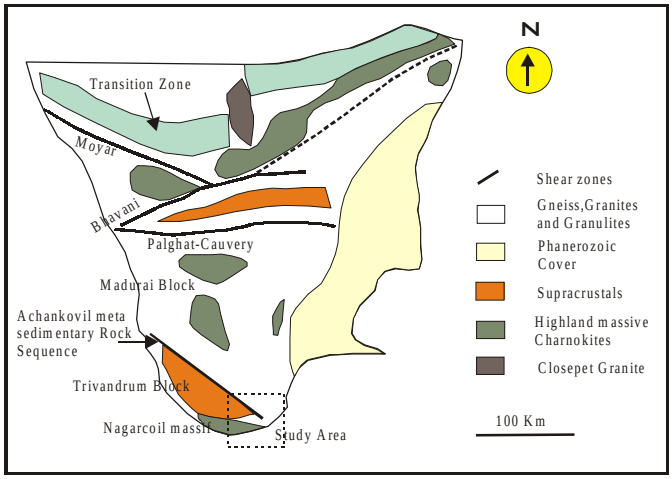
The crust of TamilNadu and Kerala is constituted by Granulites. This

granulite terrain is represented by Charnokites and Gneisses. The mineral assemblages of these rocks are same as to that of high grade lower continental crustal rocks. They are 2600 Ma old. They occupy the highlands of the Nilgiri hills and Cardamom-Palni ranges etc.,while the low land is occupied by the older high grade gneisses of the Archaean period. As these granulites are high temperature and high pressure rocks deficient in hydrous minerals, they are inferred to have originated at intermediate levels. This implies that (1) supracrustal rocks are first transported down to these levels where they are metamorphosed and the water is flushed out and (2) they are exhumed from those levels to the surface of the earth.(D.C.Mishra et al.,[11])

How did these rocks that were part of the lower crust (that is located at approx. 20-25 km deep from the earth's surface) reach their present position? Was it purely isostatic lift or a consequence of tectonic emplacement or a combination of the two or through any other mechanism? (F*or a detailed discussion on this see S.S.Rai et al., 'Granulite Evolution in South India-A Seismic Tomographic Perspective'* [12]).

Contiguous with the low-grade granite-gneiss terrain to the north, the South Indian Granulite province formed a part of the Indo-Antarctica-Madagascar metamorphic belt in the Gondwanaland. South Indian granulite province could be broadly classified into the Southern Granulite Terrain (SGT) and Eastern Ghat Granulite Terrain (EGGT) based on geographical considerations.

Tectonic Framework of the Southern Indian Granulite facies Terrane showing the Study Area



Map adapted from M.Satish-Kumar et al(2001)

The area of our interest, is located within the Kerala Khondalite Block; more specifically, this area is located at the junction among the Achankovil metasedimentary rock sequence, the Trivandrum Block and the Nagarcoil massif.

The SGT is further subdivided into three major blocks. The Northern Granulite Block(NGB) occupies the area between the Dharwar craton and the Palghat-Cauvery shear zone and defines the transition between the low- and high-grade terrains. The Southern Granulite Block(SGB) is the region between two major shear zones viz., Palghat-Cauvery and Achankovil.

To the south of Achankovil shear zone is the Kerala Khondalite Block (KKB) a seat of metasedimentary granulites.

The Kerala Khondalite Block is a large supracrustal terrane in the

southern part of the granulite facies segment of southern India. This belt is bounded on the north by the Achankovil Shear Zone and on the south by the Nagarcoil charnokite massif. The KKB is further subdivided into Achankovil metasedimentary rock sequence, the Kerala Khondalite Belt (Trivandrum Block), and the Nagarcovil massif. (M.Satish-Kumar et.al, 2001)[13]

The area of our study is located within the abovesaid Kerala Khondalite Block; more specifically, this area is located at the junction among the Achankovil metasedimentary rock sequence, the Trivandrum Block and the Nagarcoil massif.

3. Tectonic Elements of the Area [14a,b,c,d,e]***:***

Let us now consider the important lineament lines that criss cross the Tirunelveli and Tuticorin districts. Let us classify them according to their directions.

a) North-South: Krishnagiri-Thirunelveli lineament

b) Northeast-Southwest: Cuddalore-Sathankulam lineament; Manamelkudi-Cheranmahadevi lineament; Chennai-Kanyakumari lineament.

c) Northwest-Southeast: Sargur-Vilathikulam lineament; Achankovil lineament; Thenmalai-Gadana lineament; Thoranamalai lineament.

Almost all the lineaments crisscrossing this area have shown activity in the recent past.

Are the above lineaments active?

There are evidences from recent history, that these lineaments are slowly becoming active. In 1968 and 1975 earth tremors rocked Dindigul, Salem and Dharmapuri and these towns are located on the Krishnagiri-Thirunelveli lineament. It was during this period, that earthquakes rocked the vicinity of Krishnagiri almost 19 times.

A major portion of the Northeast-Southwest trending Cuddalore-Sathankulam lineament is located in between the sedimentary rocks that are located in the east and the Gneiss rocks present in the west.The earthquake of 20 June 1819, which had its epicenter between Pondicherry and Viluppuram and the earthquake of 3 July, 1867 with its epicenter in the same area are the examples which tell us that this lineament is getting activated.

Manamelkudi-Cheranmahadevi lineament with a NE-SW trend crosses the Achankovil lineament in the south. It is in the area where these two lineaments meet each other, we witnessed the 24-11-2001 Rock Melt Extrusion near Surandai.

The various earthquakes that have rocked Chennai, Thambaram, Mamandur and Ariyalur in the past occurred in the NE-SW trending Chennai-Kanyakumari lineament.

The earthquakes that hit Coimbatore in the years 1865, 1900, and 1972 occurred in the NW-SE trending Sargur-Vilathikulam lineament.

The NW-SE trending Achankovil lineament has shown that is active many times in the past. The earthquake of 27 July 1959 whose epicenter was between Kochi and Muvattuppuzha, and the earth quake of 12 December 2001 whose epicenter was near Kottayam, and the earth quake that rocked Punalur in September and November 1993 are the examples for this.

It is in the area where the NW-SE trending Thenmalai-Gadana lineament, the NW-SE trending Thoranamalai lineament, and the N-S trending Krishnagiri-Trinelveli lineament cross each other, the earthquake that rocked Nanguneri on 16 March 1881 and the one that rocked Kalakkadu-Erwadi on 26 February 2000 had their origin. It is in this area, we witnessed the RMEs in the year 1998 and 1999.

4. Aeromagnetic Evidence of the Crustal Structure of the Study Area (A.G.B.Reddi et al.,)[15]

Geological Survey of India conducted in the year 1982, the Aeromagnetic Survey for the peninsular segment south of 12^0 N latitude which resulted in the production of a map of a relatively shallow magnetic basement. A filtered (low-pass) anomaly map was also presented as a part of this exercise.This map apparently reflected a deeper simatic layer and, therefore, the Moho (~40 kilometers below the surface) by implication.

The area seems to be composed of a mosaic of independent crustal blocks involved in relative vertical movements. A graben is indicated sub-parallel to the west coast extending into the Gulf of Mannar and possibly beyond into Sri Lanka. The Palghat-Tiruchirapalli region is also downfaulted suggesting a junction of profound structural dislocation between the granulite terrane and the Karnataka craton...The gravity rise towards the TamilNadu coast (in striking contrast with the uneventful fall in magnetic value) may have to be explained in terms of lateral changes in crustal and subcrustal parameters rather than in terms of a simple rise of the Moho.

Let us note the features that may be of immense value to our work, that are presented in the shallow magnetic map (of less than 5 km depth) first. Here we see, as noted above, distinct crustal blocks that seem to have been involved in vertical movements along clearly recognisable breaks (B_1 through B_7).

...Besides the Palghat and Tiruchirappalli-Thanjavur features, two more areas are shown too have subsided. (See the Basement Magnetic Map in the next page; this map is a 3 dimensional reconstruction[16] of the 2 dimensional map presented in A.G.B.Reddi et al.,).One of these runs parallel to the Kerala Coast and is bound by the break B_1 which nearly corresponds to what has been recognised already as the Kerala lineament. The downthrow in this case appears to be of the order of 1 km. The other subsided block is a triangular region near Tirunelveli. It is bounded by the lineament B_2 and the segment of B_1. This Tirunelveli feature and the Kerala depression taken togather seem to support the idea (Katz[17],1978) of a single trough extending into the Gulf of Mannar and possibly beyond into Sri Lanka.

The central part of the area lying between Palghat and Tiruchirapalli-Thanjavur depressions in the north and the Kerala-Tirunelveli depressions in the south is an arcuate region uplifted along B1-B4 and B5 as evidenced by relatively shallow depths to the magnetic marker/basement.

We see in this Shallow Magnetic Basement Map a Break named B-2 in the layer , which corresponds to the trending pattern of the Thoranamalai Shear.

We see in the Shallow Magnetic Basement Map (which is <5 km below the surface) a Break named B-2 in the layer, which corresponds to the trending pattern of the Thoranamalai Shear.

The Filtered (low-pass) anomaly map reflects the simatic layer in the lower part of the crust; thus by implication it is a map representing the Moho layer. In this map, we see a ridge over a ridge that extends from north of Quilon in the NW-SE direction, which winds over the Kanyakumari district and then runs NE parallel to the east coast. This ridge stops at Tiruchendur. Kudankulam is located in this ridge. The ridge and the trough in question are evident manifestations, in part, of the tectonism associated with the west coast of India. Indeed, it may not be farfetched to look upon this ridge as one of a series of volcanic featurres possibly formed as a result of the northward drift of the Indian landmass.

Let us now look in the Filtered (low-pass) anomaly map. From what we have seen earlier, it seems logical to regard the filtered map (See the Filtered anomaly map in the following pages; this is a 3 dimensional reconstructed map[16] of the 2 dimensional map presented in A.G.B.Reddi et al.,) as essentially a reflection of the simatic layer in the lower part of the crust and thus, by implication, that of Moho. The following are some of the prominent features of the map:

(i) A series of highs aligned subparallel to the Kerala coast. These highs are accompanied on the eastern flank by a narrow low anomaly zone that widens out and extends beyond Tirunelveli into the sea.

(ii) A set of equatorial anomalies in the northern part of the area.

The coastal anomalies are clearly suggestive of a ridge with an associated trough. The ridge is seen to extend from north of Ernakulam through Kottayam and Trivandrum in the NW-SE direction. Beyond Trivandrum, it is found to swing almost eastward before turning parallel to the east coast for a short distance upto south of Ramanathapuram. 'There is a ridge over this baseline ridge which extends from north of Quilon in the NW-SE direction, winds over the Kanyakumari district and then takes a short course towards NE by running parallel to the east coast. This ridge stops at Tiruchendur. Kudankulam is located on this ridge. At some areas of this ridge, we see the basement rising further. This is best seen around Trivandrum in the west coast and around Manappad village in the east coast.(Manappad is around 32 kilometers north east of Kudankulam)'.

The trough indicated along the eastern flank of this ridge extends from west of Calicut (offshore) through east of Ernakulam, to east of Ponmudi and beyond. The low in Tirunelveli region and another low SW of Mandapam (in the Gulf of Mannar- east of Tuticorin and Tiruchendur) may have to be regarded as an extension of this trough into the sea. This low anomaly zone finds expression even in the basement relief map (that is Map-) as what has been designated already as the Kerala-Tirunelveli trough.

The ridge and the trough in question are evident manifestations, in part, of the tectonism associated with the west coast of India. Indeed, it may not be farfetched to look upon this ridge as one of a series of volcanic features possibly formed as a result of the northward drift of the Indian landmass.

...As we have already seen, the Kerala-Tirunelveli trough and the downfaulted blocks of Palghat and Tiruchirapalli-Thanjavur have their direct correspondence with features in the filtered map.

'We also note that the Break B-2 in the basement magnetic layer is seen in this map also as a trough that extends from Calicut

in the northwest towards Tirunelveli and then to Tiruchendur and Gulf of Mannar. This corresponds to the trendline of the Thoranamalai Shear in which Kudankulam is located.'

The above correlations between the two maps, that apparently correspond to two different levels of the subsurface, do affirm that block movements in the area must have involved the deeper simatic crust and even the underlying subcrustal layers. The ultimate subsurface picture of the area that emerges is thus one of a mosaic of independent crustal blocks involved in epiorogenic movements.

Further Conclusions:

1. This area is located in the junction among the Achankovil metasedimentary rock sequence, Trivandrum Block, the Nagarcoil massif and the sedimentaries located on the eastern side.

2. Aeromagnetic evidence shows that the RMEs that have occurred over the past 4 years have occurred in a set of three lineament lines in the crust beneath which there is a Break B_2 in the Shallow Magnetic layer of the crust. It also shows that below this area is a trough with a similar trendline and which is bounded by a ridge of Moho. It also shows us, that there is a very high ridge in the Moho 30 kilometers northeast of Kudankulam (that is beneath the Manappad village). A.G.B.Reddi et al., postulate in their article that, it may not be farfetched to look upon this ridge as one of a series of volcanic featurres possibly formed as a result of the northward drift of the Indian landmass.

Further Questions:

1. What is the nature of the Strain that the crustal plate and the mantle of this area are experiencing?

Further Works that are necessary:

1.Conducting a detailed micro-level study of the area which will undertake a very detailed Bouguer Anomaly study, Paleo-geology of the faultlines of the area, seismic tomography, Deep Seismic Sounding Study(DSS), Geodetic Positioning study etc.

2. Constructing a Crustal Model of the area using the informations that we have considered above, and the informations that shall be generated by the above research studies.This crustal model of the area should be capable of answering all the questions that this phenomenon has so far raised.

3. This crustal model should also seek to explain the correlation seen between electrical lines and volcanic extrusions.

4. It is based on this Crustal Model, the Safety Profile of the Reactors that shall be built at Kudankulam should be planned.The tools of Probabilistic Safety Analysis (PSA)[18] should be used at this juncture to ensure a maximum level of safety in these reactors.

Conducting a detailed micro-level study, constructing a Crustal Model for the area based on these studies, is the only urgent work that the NPCIL needs to undertake at present, if it genuinely wants the Kudankulam reactors to operate with a high degree of safety in this Geological environment.

Freezing the present ongoing works at Kudankulam would be a tough decision, as it involves a foreign collaborator; but taking this decision will definitely increase the esteem of the NPCIL in the minds of the Indian people; it will also help it to invent the design solutions that shall avoid a major misery that might occur because of a Core Melt Accident due to a possible Rock Melt Extrusion beneath the Core of one of these reactors!

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Appendix

1. Site Specific Engineering Design

The International Atomic Energy Agency (IAEA) conducted a seminar on the "Seismic Evaluation of the existing Nuclear Facilities", at Vienna on 25-27 August 1997. The papers presented in this seminar were published in March 2001. A. Camino of the Division of Nuclear Installation Safety of the International Atomic Energy Agency who spoke in this seminar, made the following statement in 1997:[1]

"The future of nuclear energy depends on three main factors, namely:

1) Nuclear Safety: prevent accidents and demonstrate excel lence in safety (Safety Culture)

2) Economics: electricity deregulation, modernization and life extension of existing (old) plants, decommissioning, and

3) Public Acceptance."

P.C. BASU of the Civil & Structural Engineering Division, of the Atomic Energy Regulation Board, Mumbai, India stated in the same seminar:

"Earthquakes have the potential to induce common cause failure. The frequency and severity of seismic hazard is site related. Measures for protection against seismic hazard are incorporated into the plant design. Plants built using earlier standards may have deficiencies both in the requirements relating to the derivation of design basis ground motion (DBGM) as well as in criteria and measures (i.e. design features) for protection against the effects of seismic hazard. In view of this, it is necessary to re-evaluate the capability of the structures, systems and component (SSC) of older facilities to withstand the effect of earthquake in line with the current criteria."